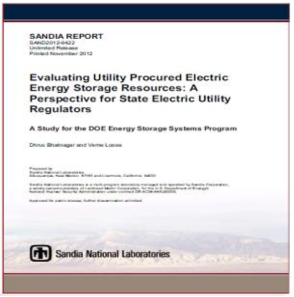

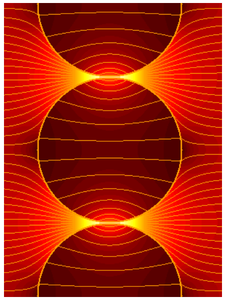

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Protocols and Procedures for Grid-Level ESS

David Rosewater

for David Schoenwald

Presentation for

EMA Energy Storage Workshop

Singapore

August 2015

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration   SAND Number: 2015-6311C

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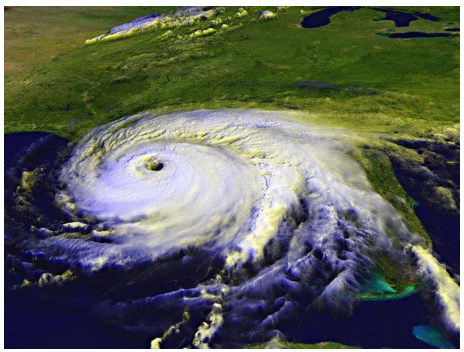

ESS Performance Protocol Development

September 19, 2014

Dave Schoenwald (SNL), Dave Conover (PNNL), Vish Viswanathan (PNNL)

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Special acknowledgement to other presentation authors:

- Dave Conover (PNNL)
- Vish Viswanathan (PNNL)

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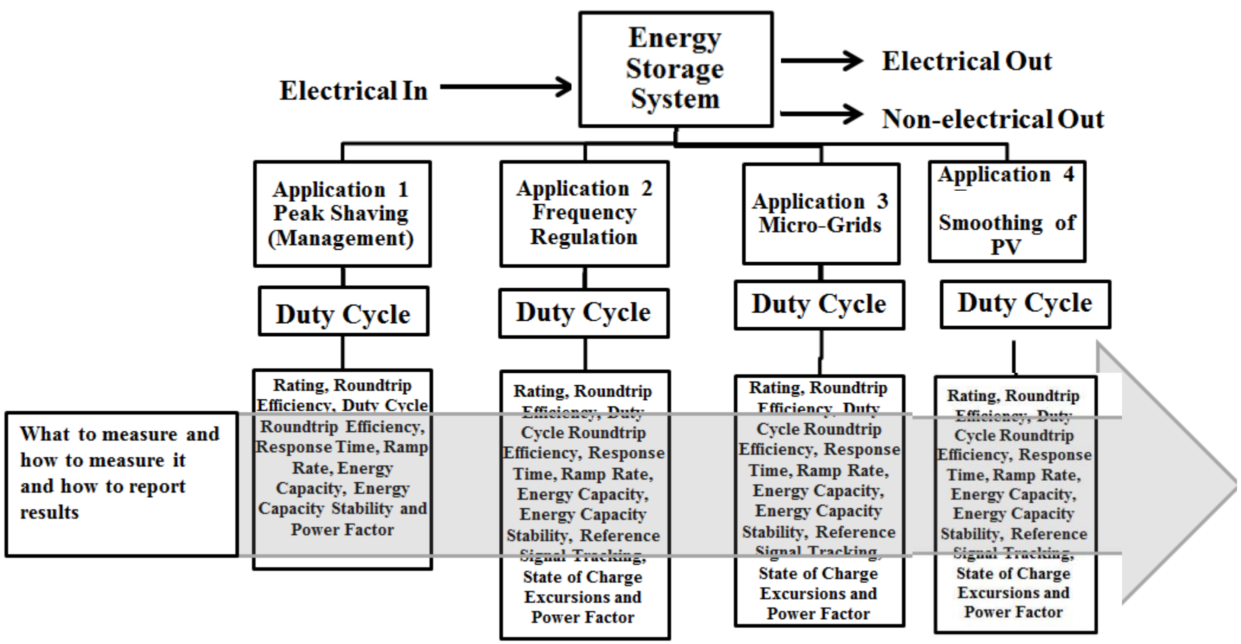
Background and Needs

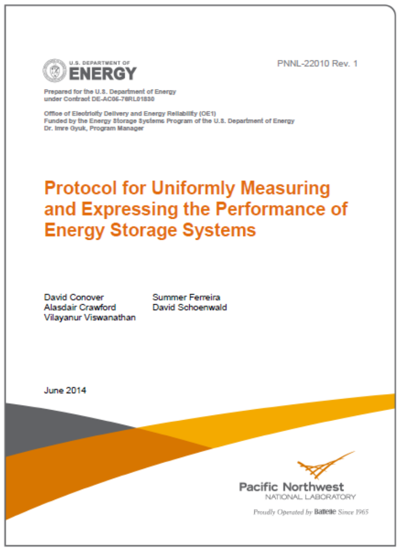
- There is significant activity to deploy energy storage technology and foster its acceptance
- In the absence of an agreed upon set of criteria for measuring and expressing system performance…
  - manufacturers have to develop their own criteria
  - it is a challenge to compare the performance of different systems
  - customers may make up their own criteria and as a result force re-testing
  - deployment of ESS are more costly and time consuming

✓ The storage industry and its customers/users need **uniform** ways of measuring performance

Protocol for Measuring and Expressing ESS Technology Performance

- first protocol was published in 2012
- broad scope and purpose
- criteria covering two energy storage applications
- room for growth to address additional applications
- microgrids and technical enhancements added in June 2014
- PV smoothing added with anticipated re-publication in late 2014




U.S. DEPARTMENT OF ENERGY

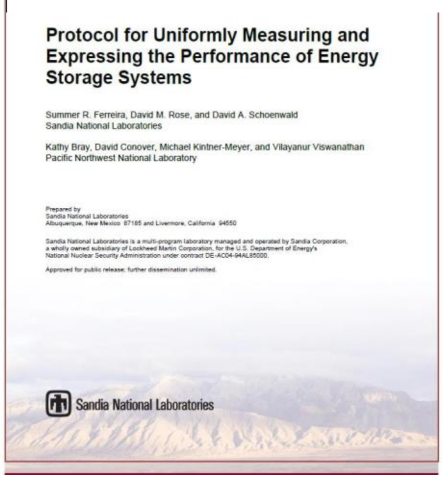
PNNL-22010 Rev. 1

Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems

David Conover
Alasdair Crawford
Vilayanur Viswanathan
Summer Ferreira
David Schoenwald

June 2014

Pacific Northwest NATIONAL LABORATORY


Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems

Summer R. Ferreira, David M. Rose, and David A. Schoenwald
Sandia National Laboratories

Kathy Bray, David Conover, Michael Kintner-Meyer, and Vilayanur Viswanathan
Pacific Northwest National Laboratory

Sandia National Laboratories

FY14 ESS Protocol Accomplishments

- Initiated a protocol users group to test drive the protocol and provide ongoing feedback that can be used to inform future protocol enhancements
- Added thermal storage systems for peak shaving applications
- Added two new applications to protocol
  - Micro-grids
  - PV Smoothing
- SDOs strongly considering ESS protocol as a basis for new standards in ESS performance
  - NEMA (U.S.)
  - IEC (International)

ESS Protocol users group

- Input from the users group was one of the primary **enhancements** added to the June 2014 Protocol
- Consists of members of the ESS Protocol Working Group, who have agreed to **"test drive"** the 2012 Protocol and provide feedback about their experiences
- This **feedback** has helped to:
  - refine the performance measurement and expression criteria to make them easier and less time consuming to apply
  - enhance the accuracy of the results
  - ensure that the metrics are equally applicable to all systems (e.g., do not support one system type over another)

Thermal storage group

- Focuses on effectively addressing **thermal storage systems** within the ESS protocol
- Enhancement added for 2014 was **peak-shaving** applications
- Consistency in how the document refers to what is measured and reported is achieved by **clearly defining electrical and thermal energy:**
  - Input to/output from the ESS at any instant is **power** ($V \times I$)
  - Cumulative input to/cumulative output from the ESS over time is **energy** ($V \times I \times t$)
- Whenever the criteria specifically refer only to electrical or thermal systems, the terms electrical or thermal are used to qualify power or energy

Microgrid working group

- Working group had 30 members
- National labs, Utilities, Storage vendors, Controls, SDOs, Testing laboratories, Integrators
- 10 web meetings, multiple email exchanges
- Microgrid exchange group definition adopted:

  "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the main grid and can connect to and disconnect from the grid to enable it to operate in either grid-connected or island mode"

Microgrid overview

- Typical microgrid is connected to the main grid and operates in islanded mode as the need arises
- Requires consideration of all grid applications and islanded mode applications
- The ESS Protocol Microgrid Sub-group decided to consider the microgrid operating in an islanded mode
- Three different scenarios
  - With renewables
  - With renewables, but no frequency regulation
  - Without renewables and without frequency regulation

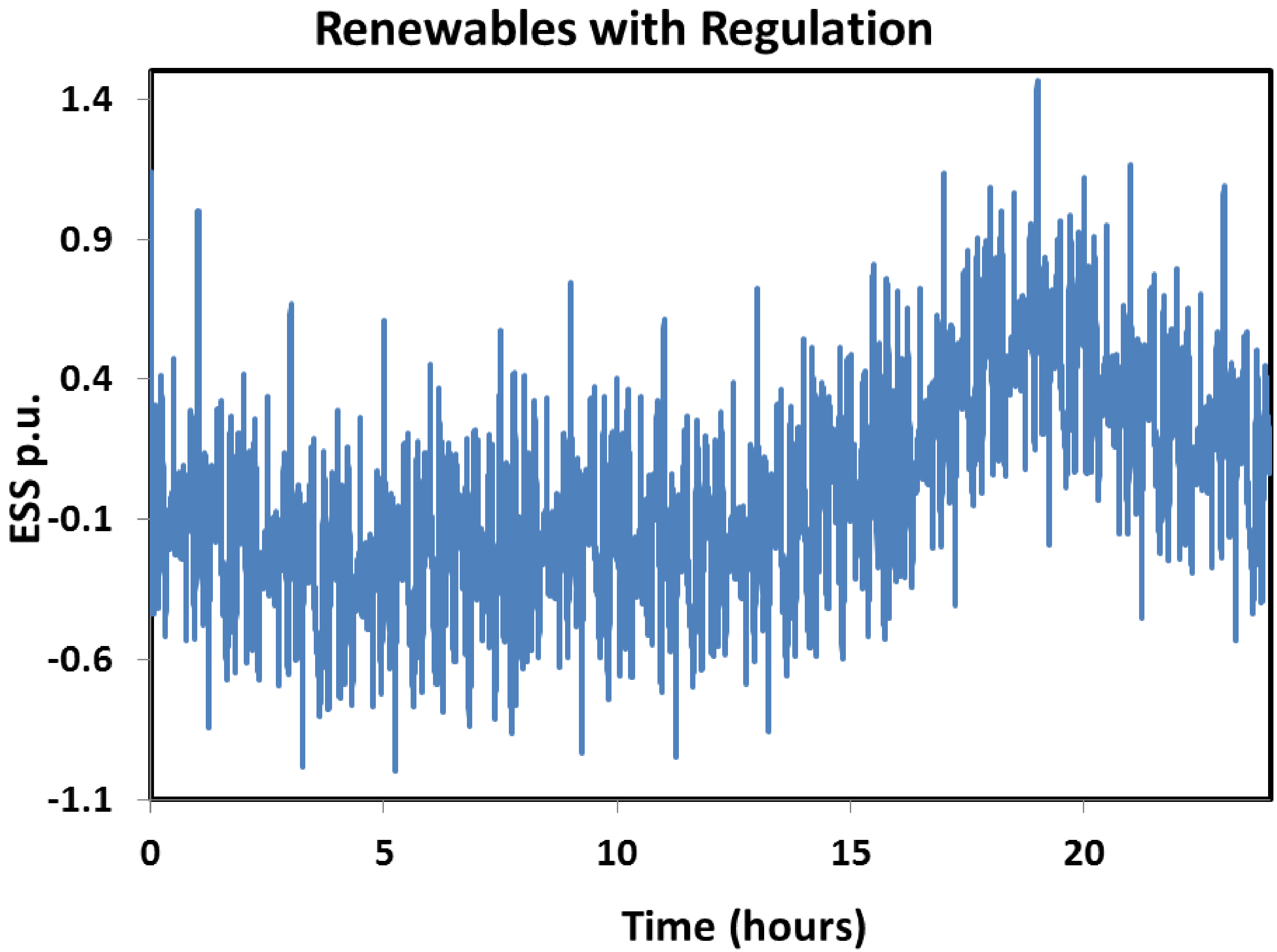
Microgrid use cases

- Use cases
  - Frequency regulation
  - Renewable smoothing
  - Volt/Var support
  - Power quality
  - Frequency response
  - Black start
- Assumptions
  - Critical load is 25% of peak load
  - Maximum wind and solar generation is 35% (each) of peak load
  - Wind generation data provided by a South Central Washington State commercial wind generation facility
  - Solar output and load at the Rankine Avenue Substation in Mount Holly, NC used (Dan Sowder, 2013)
  - Night load taken from the literature (Pipattanasompom et al. 2011)
- Details found in PNNL-23390 and PNL-22010 Rev 1

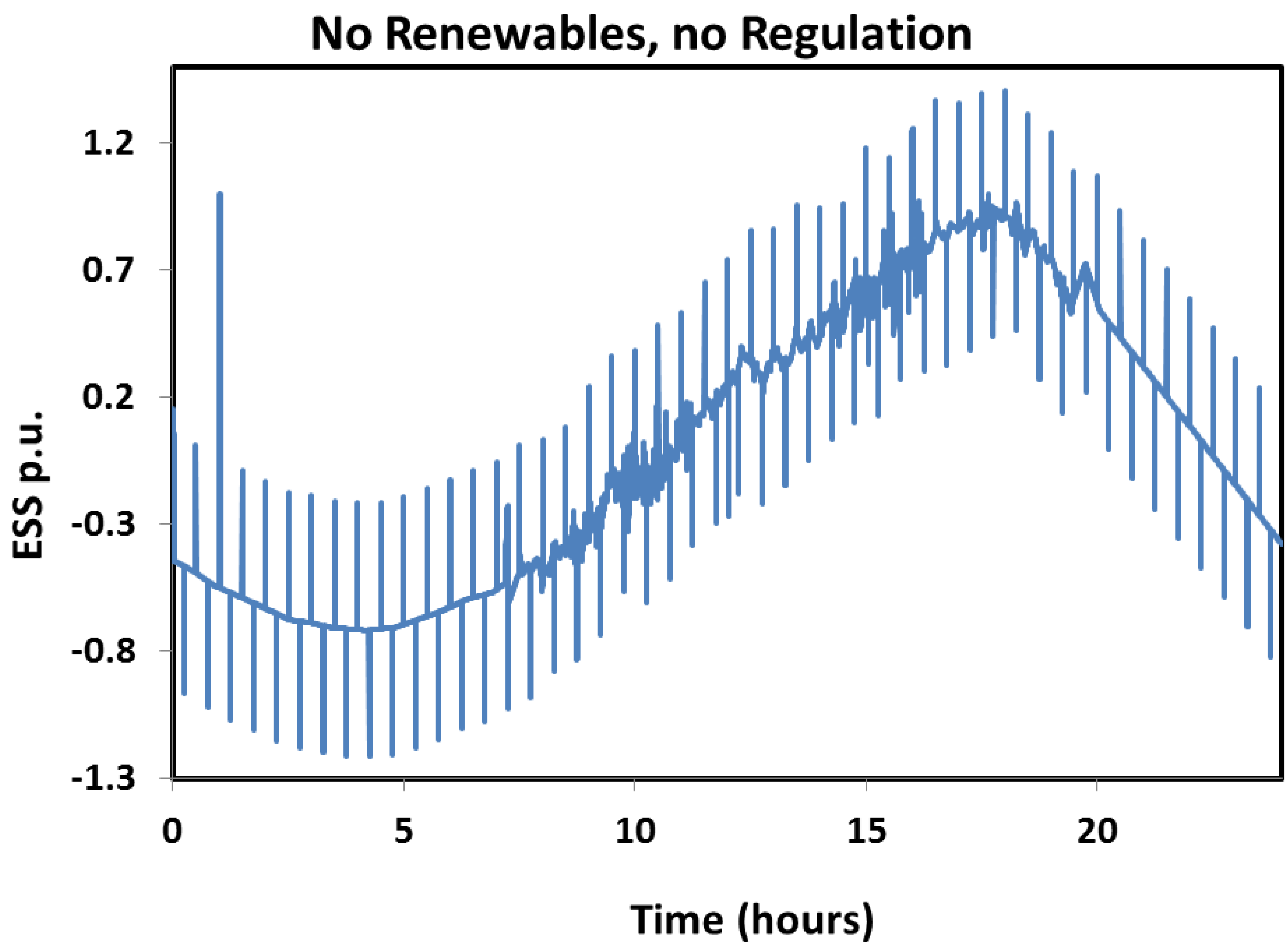
Performance Metrics

- Round trip efficiency
- Duty cycle round trip efficiency
- Response time and ramp rate
- Energy capacity
- Energy capacity stability
- Reference signal tracking
- State of charge excursion
- Power factor

Duty cycle A – Renewables with regulation



Duty cycle C – No Renewables, no frequency regulation



Reporting results

Table 8.1.1. Stored Energy Capacity and Roundtrip Efficiency at Rated Power

	Charge Energy (Wh)	Discharge Energy (Wh)	Roundtrip Efficiency
Cycle 1	______	______	
Cycle 2	______	______	
Sum			

Table 8.3.2. Roundtrip Efficiency Test for Microgrid Duty Cycles

Duty Cycle	Charge Energy (Wh)	Discharge Energy (Wh)	Duty Cycle Roundtrip Efficiency
First			
Second			
Third			

Table 8.3.4. Reference Signal Tracking Test for Microgrid Duty Cycles

Duty Cycle	$\Sigma(P_{signal} - P_{ess})^2$ ($watts^2$)	$\Sigma\|P_{signal} - P_{ess}\|$ (watts)	$\Sigma\|E_{signal} - E_{ess}\|$ = (Wh)	% of time signal is tracked
First				
Second				
Third				

Response time and ramp rate

Discharge response time = -----seconds

Discharge ramp rate = ------- MW/min and --------% rated power/min

Charge response time = -----seconds

Charge ramp rate = ------- MW/min and -------% rated power/min.

SOC excursion

Lowest SOC, renewables with frequency regulation –

Highest SOC, renewables with frequency regulation –

Lowest SOC, renewables without frequency regulation –

Highest SOC, renewables without frequency regulation –

Lowest SOC, no renewables and no frequency regulation –

Highest SOC, no renewables and no frequency regulation –

PV Smoothing working group

- Working group has 22 members
- National labs, Utilities, Storage vendors, Controls, Integrators
- 6 web meetings, multiple email exchanges
- Working Group is finalizing duty cycle for ESS protocol

Definition of PV Smoothing

- PV Smoothing – the use of an energy storage system (ESS) to mitigate **rapid fluctuations** in variable photovoltaic (PV) power output
- Purpose:
  - To mitigate frequency variation and stability issues that can arise at both feeder and transmission level in **high penetration PV** scenarios
  - To help meet ramp rate requirements
  - Feeder level – To mitigate voltage flicker and voltage excursions outside desired bands
  - Transmission level – PV variability can require additional operating reserve to be set aside and can cause traditional generation to cycle more than otherwise
- Method:
  - ESS is used to absorb or supply power at appropriate times as determined by a control system resulting in a less variable composite power signal at feeder and/or transmission level

Metrics

List of needed metrics:

1. System Rating – @ ambient conditions
2. Roundtrip Energy Efficiency – for entire ESS
3. Duty-Cycle Roundtrip Efficiency "
4. Response Time of ESS in responding to a command signal – does not include communication delay times
5. Ramp Rate
6. Energy Capacity
7. Energy Capacity Stability
8. Reference Signal Tracking – how well does ESS track the reference signal; metric definition is: |reference signal power – ESS power|^2
9. State-of-Charge Excursions
10. Power Factor – measure of inverter performance

PV Smoothing Duty Cycle

- What is basic time length of duty cycle?
  - 8 to 10 hours should be sufficient
- What key features should duty cycle capture?
  - Basic idea is to capture 1-2 hour “slices” of typical PV generation obtained from different days and splicing them together, rather than trying to find one day that has “everything”.
  - These “slices” should try to capture different scenarios such as mostly sunny, partly cloudy, and mostly cloudy days.
  - Different regions and times of year would be captured in one signal rather than having multiple duty cycles.
- Time resolution of data?
  - 1 second data is needed
- Do we need multiple scenarios as with microgrids?
  - One duty cycle should capture most situations.

PV Power Output Data Source

PNM Prosperity Electricity Storage Project

- ARRA project which includes PNM, UNM, NNMC, SNL, East Penn, S&C Electric, EPRI
- We have permission (from Public Service Company of New Mexico – PNM) to use:

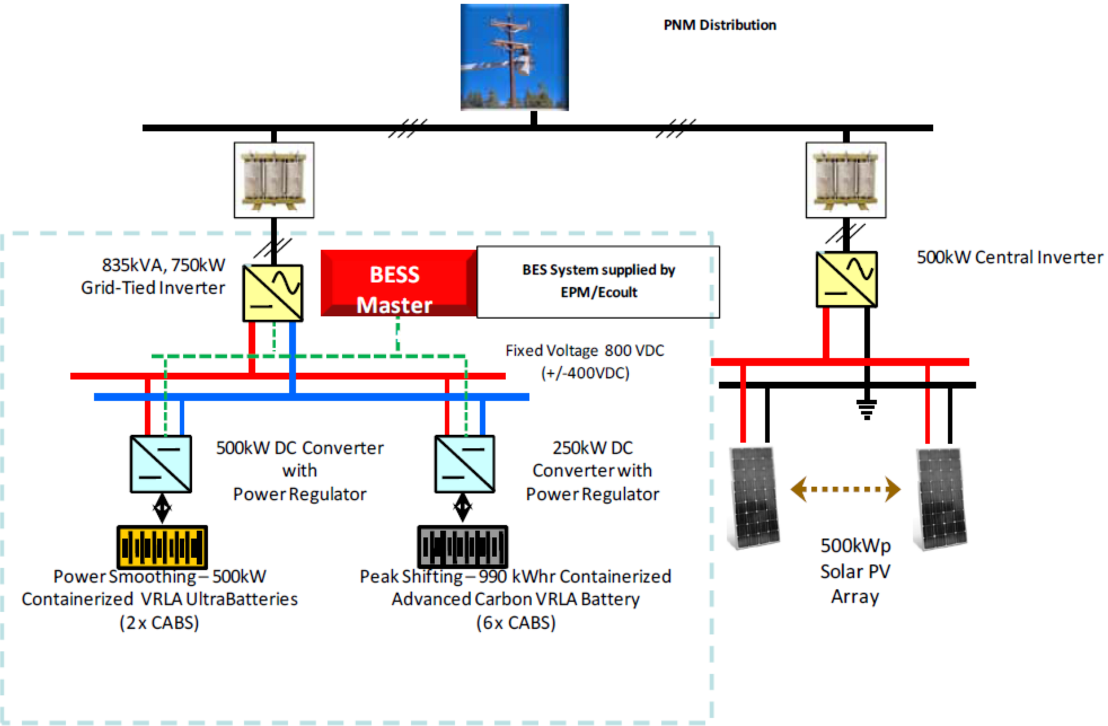
– PV power output, kW

– Battery power output, kW

- Data features

– Archived from 2011 onward

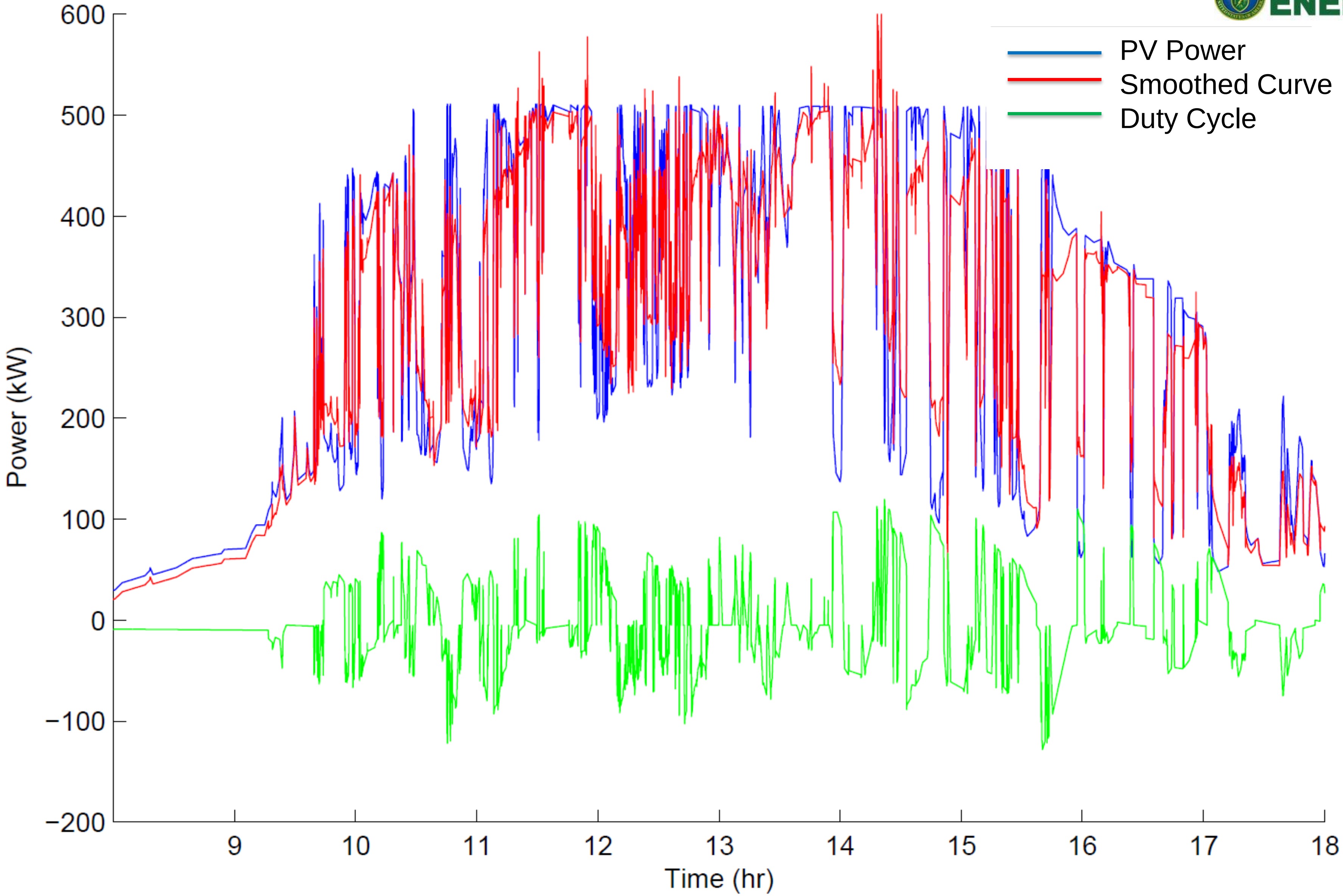
– One second time resolution



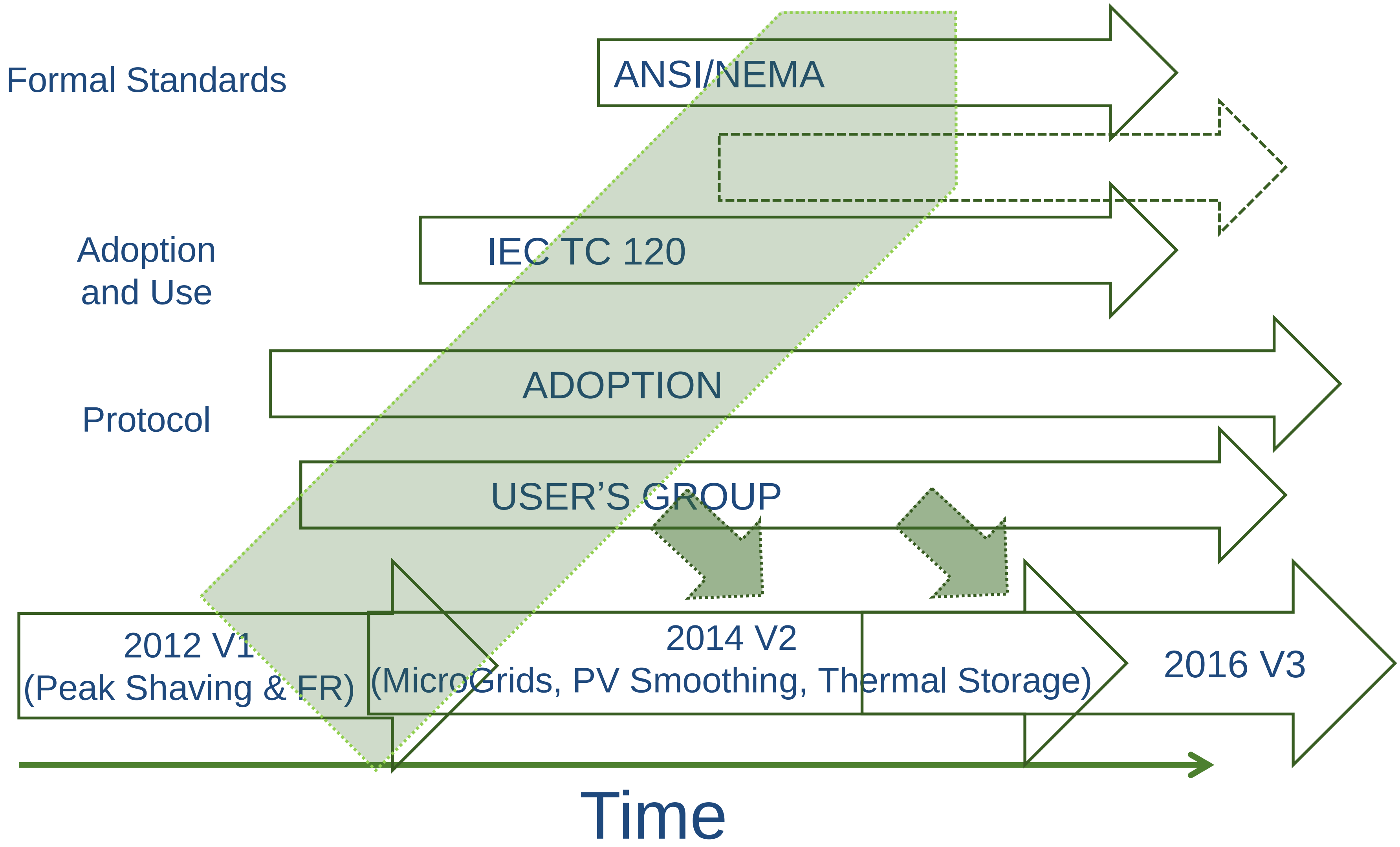
Duty Cycle Construction Process

- Purpose of Smooth Curve is to ensure that storage device will be responding to the “deltas” in PV variability from some nominal profile
- Smooth Curve can be visualized as the desired power output of a “peaker” plant with the smoothing battery then focused on mitigating the “excursions” – Note that smooth curve needs to be just that, no more than some allowable ramp rate that a peaker plant can handle.
- Battery will both charge and discharge in following duty cycle
- Power curves should be normalized (0 to 100%) such that they are invariant to battery power and energy ratings

Example Duty Cycle from "High" PV Variability



Fostering Future Enhancements



Questions?

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